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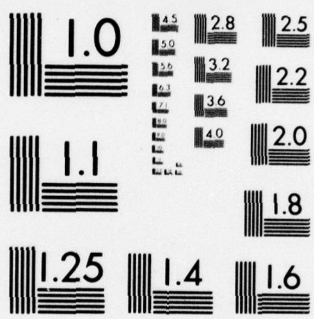
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OBSERVATIONS ON VERTICAL PROFILES OF THE SNOW COVER ON ROOFS AND MELTING AT THE BOTTOM OF THE SNOW COVER

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CRREL

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Observations on vertical profiles of the snow cover on nearly flat roofs of three different buildings of this Branch were made on January 13, 1977, and the observational results were compared with that of the snow cover on the ground. Relative positions of the observational points are shown in Figure 1. The rate of the increase of the snow cover on the ground due to the fall of the daily new snow is shown in Figure 2. Comparison of these four results revealed that the layered structure of the snow cover on flat roofs is similar to the upper

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20. Abstract (cont'd)

part of the snow cover on the ground, and a granular snow layer was observed at the bottom of each snow cover. These two facts mean that each snow cover melts at its bottom due to the heat flow either through the ceilings of the buildings or through the ground surface. The thawing rate of the snow cover on the roof of the main building of the Branch reached the value of 2.9 mm per day which corresponds to the heat flow of 23 cal cm^{-2} day^{-1} as shown in Table 1. Snow load on the roofs of the main building and the storehouse without any heater was 130 and 190 kgf m^{-2}, respectively, and this difference of 60 kgf m^{-2} is a considerable amount of snow in the designing of the building construction. Snow cover on the ground melted by 0.61 mm day^{-1} due to the heat flow through ground surface, and the amount of the heat necessary to melt the snow corresponds to 4.9 cal cm^{-2} day^{-1}. On the other hand, the measurements of the heat flow from the ground in the observational field of the Branch showed that the amount of heat, 6.4 cal cm^{-2} day^{-1}, came up through the ground in the period from December 9, 1976 to January 13, 1977, and this amount nearly equals to the calculated result, 4.9 cal cm^{-2} day^{-1}.

OBSERVATIONS ON VERTICAL PROFILES OF THE SNOW COVER ON ROOFS AND MELTING AT THE BOTTOM OF THE SNOW COVER

Tsutomu Nakamura and Osamu Abe

SOURCE: Research Reports of the National Center for Disaster Prevention, No. 19, March 1978, pp. 219-228.

Introduction

There has been considerable research on dealing with roof snow. However, there has been little study of the characteristics of roof snow covers and of the characteristics of the interior regions of the snow covers on flat roofs in particular. While knowledge about weight only is sufficient in considering problems of roof snow loads, a knowledge of the interior state of the roof snow cover is important in studies of methods for dealing with it.

This winter (the winter of 1976-1977), the authors made a study of the so-called "vertical profiles" of the snow covers on flat roofs. We are reporting on our findings here.

1. Date and Places of Observations

Observations were made of the vertical profiles of the roof snow covers on three buildings at this Center on 13 January 1977. Figure 1 shows the relative positions of the three buildings, which were the Center office building, the observation room and the equipment storehouse. As can be seen from the figure, the equipment storehouse is located downwind from the office building in respect to winter seasonal winds. The heights above ground level of the office building, the equipment storehouse and the observation room are 9.7 meters, 5.7 meters and 3.8 metrs, respectively. Their slopes are, respectively, 8/100 (so-called 0.8 sun* slope, the same applying to the following figures), 4/100 and 2/100. In Figure 1, the descending directions of the slopes are indicated by arrows. The roofs of the office building and the equipment storehouse are made of long gauge iron sheet and the roof of the observation room

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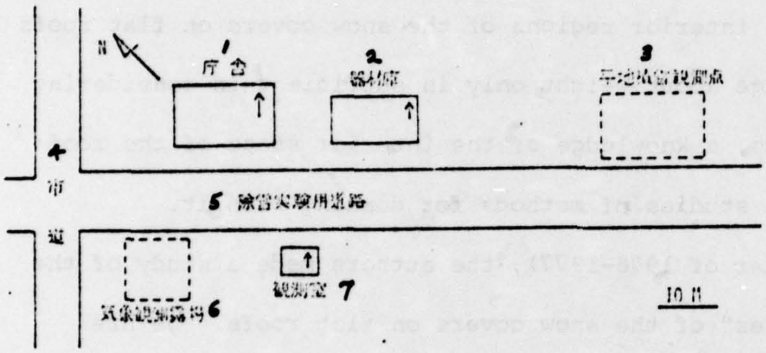
*1 sun = 1.193 inches. --Translator.

FIGURE 1:

Relative positions of the three buildings and the ground where the snow cover observations were made



1 - Office building
2 - Equipment storehouse
3 - Ground snow cover observation point
4 - City road
5 - Road for experiments on snow removal
6 - Open area for meteorological observations
7 - observation room

is made of concrete and mortar.

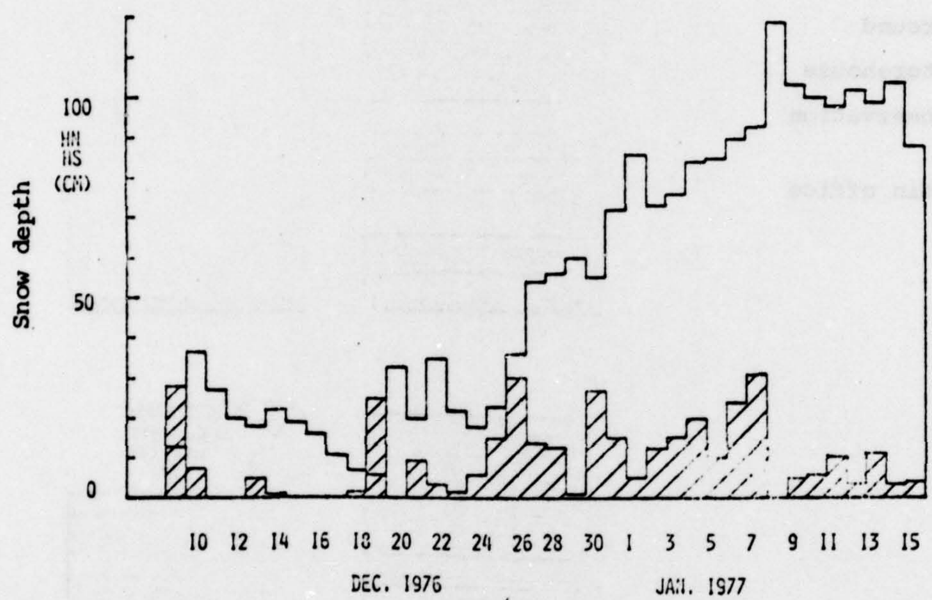
The method of observation was the same as that for the observation of vertical profiles of snow covers on the ground. The profile was taken in a direction perpendicular to the slope of the roof.

2. Results of Observations

Figure 2 shows the daily new snow falls and increases in depth of the snow cover up to 2 days after 13 January, the day of observation. Maximum daily snowfall in January was about 30 cm. Snowfalls of this extent occurred on 4 days between 9 December and 13 January. Although there was a gradual increase

FIGURE 2:

Snow falls and snow cover (diagonal lines indicate depths of snow cover)



in the depth of the snow cover beginning in late December, there were no significant snowfalls over periods of 13 days before and after the day of observation, this period having been one of essentially stable snow cover depths.

Figure 3 shows the layered structures of the snow cover profiles for the three aforementioned buildings and the ground. The results of the observations for the ground are the values obtained on the day following that of our observations, that is, the 14th [Higashiura et al. (personal communication). The same applies to subsequent results of observations of the vertical profiles of ground snow cover.). From the vertical profile photographs, it was found that the snow cover was generally made up of 2 to 3 layers. Figures 4 through 7 show the details of these findings.

FIGURE 3:

Layered structure of the snow cover

1: On the ground

2: On the storehouse

3: On the observation room

4: On the main office building

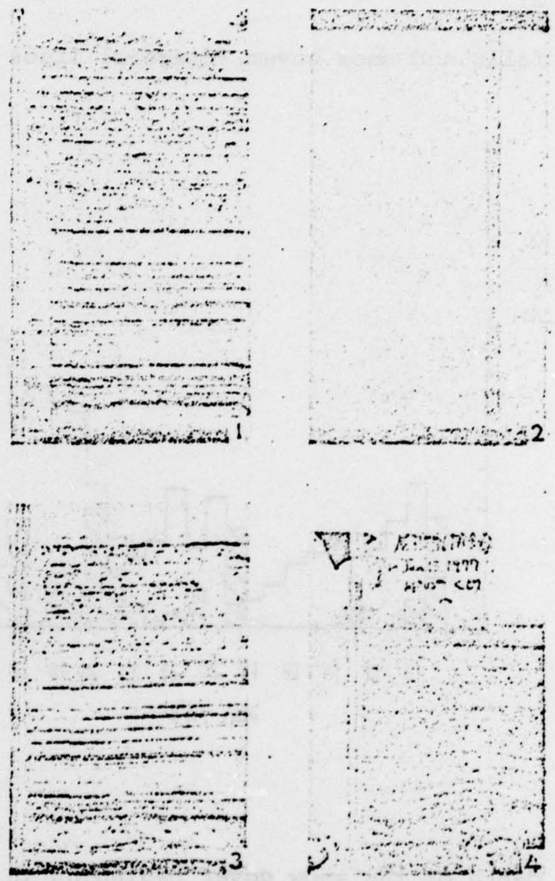
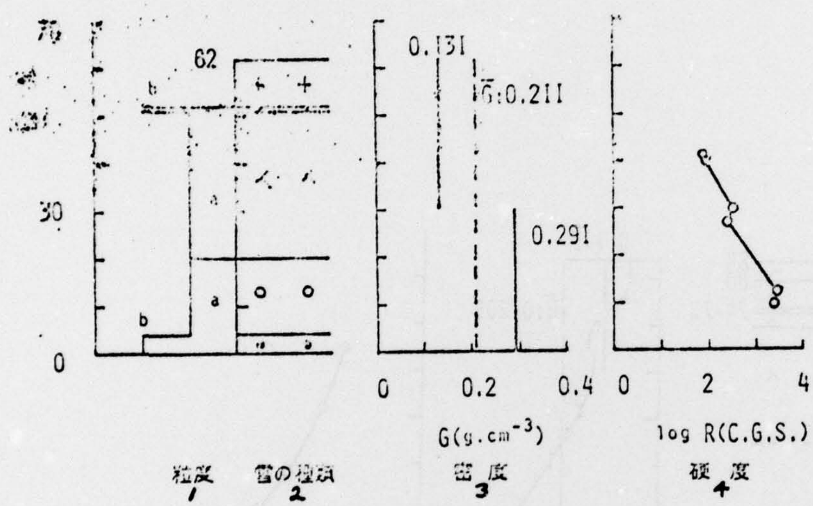


FIGURE 4:

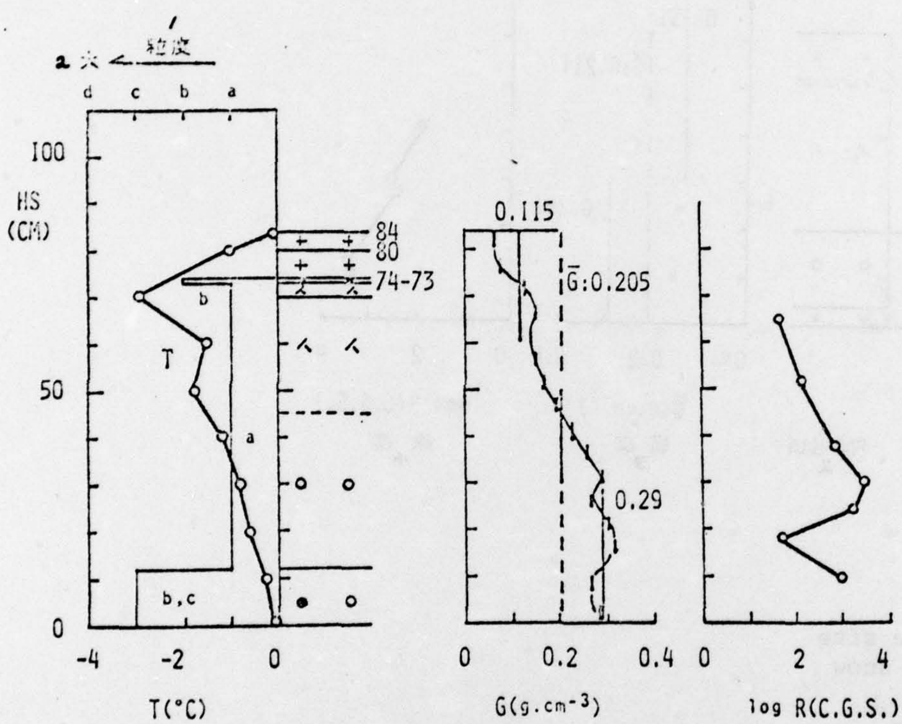
Results of observations of the vertical profile of the snow cover on the roof of the main office building (symbols are international symbols[4])



1 - Particle size
2 - Type of snow
3 - Density
4 - Hardness

FIGURE 5:

Results of observations of the vertical profile of the snow cover on the roof of the observation room (T indicates temperature; other symbols the same as in Figure 4)



1 - Particle size
2 - Large

FIGURE 6:

Results of observations of the vertical profile of the snow cover on the roof of the equipment storehous (symbols the same as in Figure 4)

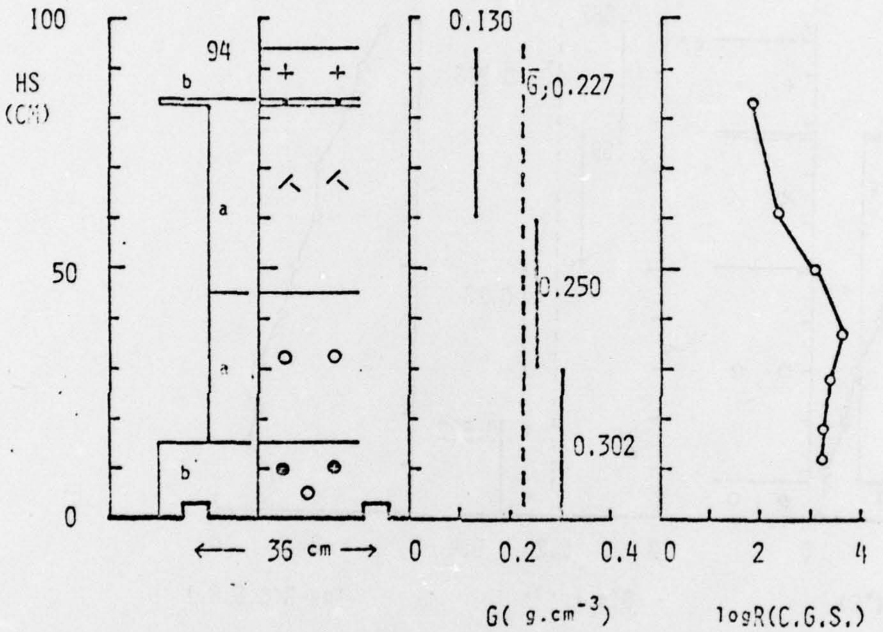
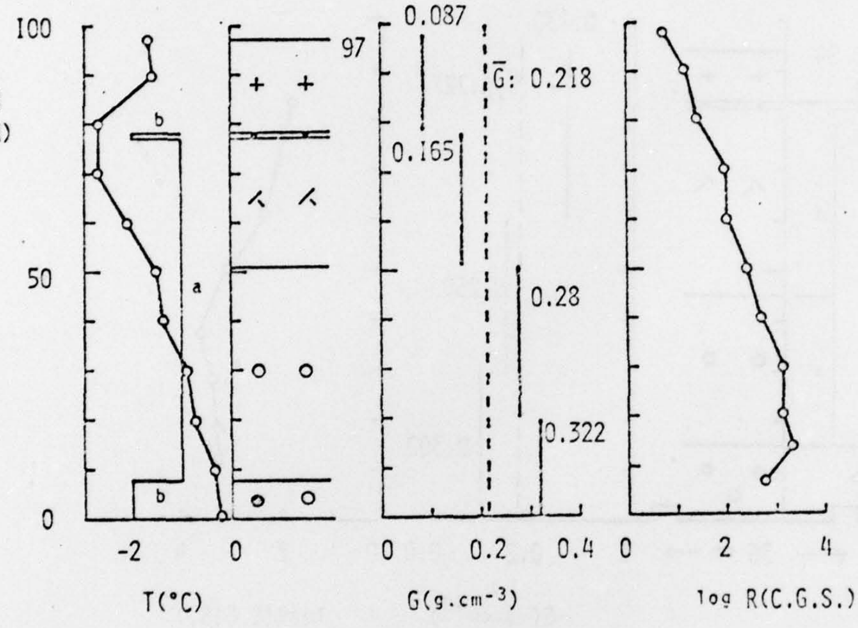


FIGURE 7:

Results of observations of the vertical profile of the snow cover on the ground (symbols the same as in Figure 4)

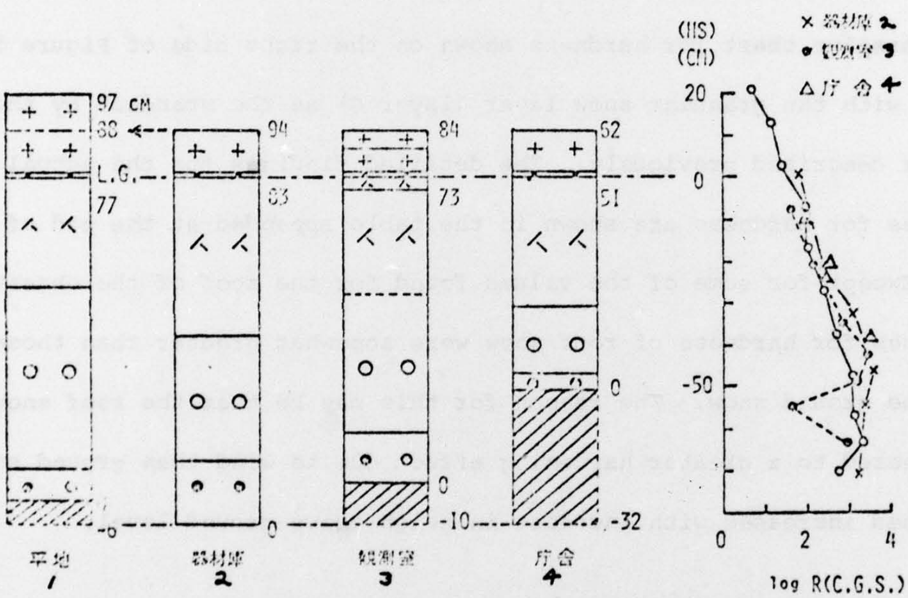


Various physical quantities in addition to layered structure are shown in Figures 4 through 7. Although the findings for particle diameters, snow temperatures, order of the layers of the snow and mean densities were highly similar, differences were found in harness and depth of snow cover. Figure 8 shows comparisons of these findings. Fortunately, there was in all cases a thin granular layer (designated as layer G) at about 10 cm below the surface of the snow cover. Therefore, this layer was taken as the standard site for

FIGURE 8:

Comparison of the snow covers on the the roofs of the three buildings and the snow cover on the ground (symbols the same as in Figure 4)

Enclosure of the symbol HS in parentheses indicates that the standard surface was 11 cm below the surface of the snow cover.



1 - Ground
2 - Equipment storehouse
3 - Observation room
4 - Main office building

comparison in preparing Figure 8. The depth of the snow cover on the ground is the value obtained for 14 January. Therefore, the depth of the snow cover on the ground on the 13th was taken to be 88 cm, which was the value obtained by subtracting the depth of the snowfall from the 13th up to the 14th. This

was the standard for subsequent comparisons. The snow cover was thickest on the roof of the equipment storehouse. With this as a standard, the depths of the snow covers on the other buildings were less than that on the roof of the equipment storehouse, being 32 cm on the main office building and 10 cm on the measurement room, whereas the ground snow cover was 6 cm.

The comparative chart for hardness shown on the right side of Figure 8 was prepared with the granular snow layer (layer G) as the standard by the same method as described previously. The detailed findings for the actual measured values for hardness are shown in the table appended at the end of this paper. Except for some of the values found for the roof of the observation room, the values for hardness of roof snow were somewhat greater than those for that of the ground snow. The reason for this may be that the roof snow cover is subjected to a greater hardening effect due to wind than ground snow since wind speed increases with increase in heigh above ground level.

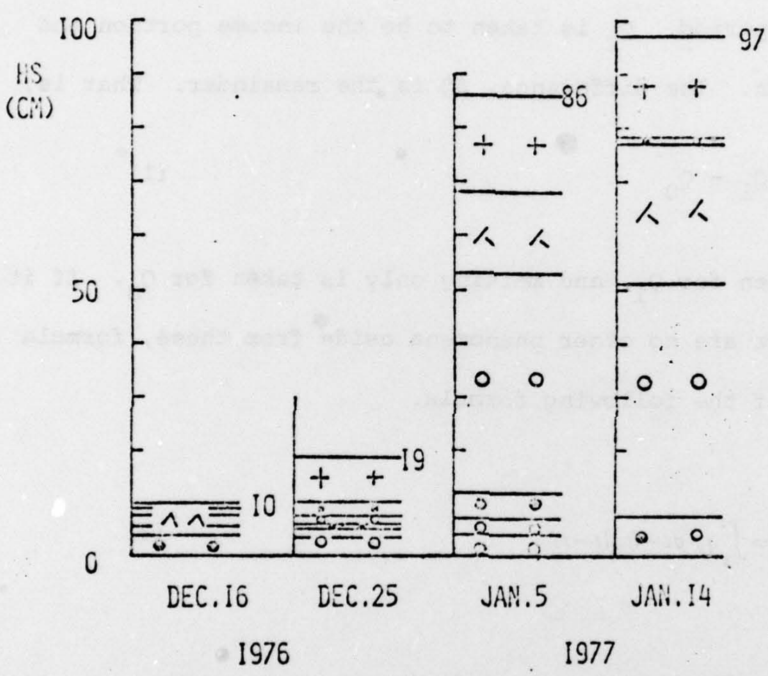
3. Thawing at the Base of the Snow Cover

The equipment storehouse was not heated, whereas the observation room was occasionally heated and the main office building was heated every day during the daytime except on Sundays and holidays. On the ground, there was a certain amount of terrestrial heat flux. The terrestrial heat flux from 9 December up to 13 January, which was the day of observation, was a constant value of 6.4 cam cm^{-2} day^{-1}.* Therefore, the reason for the differences in depth of snow cover at the four sites as described previously was largely thawing from the

*This value was determined at the open area for meteorological observations of this branch using heat flow plates.

FIGURE 9:

Changes over time in the layers of the ground snow cover (symbols the same as in Figure 4)



base of the snow cover. The fact that there were only very slight amounts of granular snow in the bottommost layer of the snow is a further confirmation of this point.

Figure 9 was prepared (by Higashiura et al.) in order to ascertain the character of changes over time in the ground snow cover and particularly of the snow cover in the vicinity of the ground. From this figure it can also be seen that there were slight amounts of melting near the ground.

For this reason, we decided to consider the quantity of thawing at the base of the snow cover up to 13 January. As we have discussed in general terms on a previous occasion, we can consider income and outgo of the quantity of the snow cover for a certain period. Q_I is taken to be the income portion and Q_0 to be the outgo portion. The difference, ΔQ is the remainder. That is,

$$\Delta Q = Q_1 - Q_0 \tag{1}$$

Snowfall only is taken for Q_1 and melting only is taken for Q_0. If it is then assumed that there are no other phenomena aside from these, formula (1) can be written in terms of the following formula.

$$\Delta Q = \int_{t_0}^{t} q_p \cdot dt - \bar{q}_m (t - t_0) \tag{2}$$

In this formula, q_p is volume of snowfall per day, $\bar{q}_m$ is average quantity of melting per day and t is time. For the sake of simplicity, the volume of snowfall used in subsequent calculations is the value converted in terms of water.

q_p in formula (2) is a function of the time, t. Although it is difficult to determine its shape, the integral value can be found by summing the values determined for quantity of snowfall for each day. That is, since the period after 9 December was one of continuous ground snow cover, t_0 was taken as 9 December and t was taken as 12 January. When the first term on the right side on the right side of formula (2) was found from the determined values using total rainfall and snowfall, a value of 235.5 mm was obtained. This is the

value for the 35.5 day period from 9 December 1976 to noon of 13 January 1977.

The second term in formula (2) can be found as the difference between the determined values ΔQ at each observation point and the aforementioned first term. Here, ΔQ is the relative water content of the snow cover and is found as the product of the snow cover depth and the density of the snow. Table 1 shows the results.

The daily thawing rates at each observation point were calculated as 2.9 mm for the roof of the main office building, 1.8 mm for the roof of the observation room, 0.62 mm for the roof of the equipment storehouse and 1.2 mm for the ground. The amounts of heat required to melt quantities of snow cover comparable to these values are shown in Item 6 of Table 1. In calcultating these heat quantities, the quantity of heat required to raise the temperature of the snow cover to 0° C was ignored.

The aforementioned quantities of melted snow drained out along the gently sloped surfaces of the roofs.

Since the equipment storehouse was not heated, we believe that the thawing of the snow on its roof was due to the energy of the sunlight absorbed by the building and the heat energy that was derived from the atmosphere. The amounts of heat energy absorbed by the buildings differed depending on the area of the building, the surface materials and the direction in which the building faced. If we tentatively assume that all three buildings absorbed the same quantities of heat, then, as shown in Item 7 of Table 1, by setting the snowmelt of the equipment storehouse at 0, the snowmelt (which is called the relative snowmelt) can be calculated in terms of terrestrial heat only for the ground and in terms of residual heat influx from heating for the observation room and the main office building.

TABLE 1:

Snowmelt volumes, melt rates and heat flux rates calculated for ground snow cover and roof snow covers

Item \ Observation point		Ground	Equipment storehouse	Observation room	Main office building
1	Snow depth on 13 January, HS (cm	88	94	84	62
2	Average snow density on 1 January, $\bar{G}$ (g cm^{-3})	0.218	0.227	0.205	0.211
3	Water equivalent of snow, ΔQ = (HS) x $\bar{G}$ (mm)	191.8	213.4	172.2	130.8
4	Total snowmelt, 235.5* - ΔQ (mm)	43.7	22.1	63.3	104.7
5	Average daily thawing rate (mm day^{-1})	1.2	0.62***	1.8	2.9
6	Average daily amount of heat necessary for thawing per unit area of ground, (cal cm^{-2} day^{-1})	9.6	5.0***	14.4	23.2
7	Relative snowmelt** (mm)	21.6	0	41.2	82.6
8	Relative average daily thawing rate (mm day^{-1})	0.61	0	1.2	2.3
9	Ground heat and heat flux through roofs (cal cm^{-2} day^{-1})	4.9	0	9.6	18.4

*235.5 mm was the total amount of precipitation from 0 hours on 9 December 1976 up to 1200 hours on 13 January 1977.

**Values obtained by setting the snowmelt on the roof of equipment storehouse at 0.

***Of the total amounts of sunlight energy and heat energy absorbed by the energy storehouse, the quantity of heat required to melt the snow cover and the thaw rate due to it

Heat is required in order to melt snow covers corresponding to these values. Whereas the terrestrial heat flux on the ground was 4.9 cal cm^{-2} day^{-1}, the values for heat flux passing through the roofs via the ceilings were 9.6 and 18.4 cal cm^{-2} day^{-1} for the observation room and the main office building, respectively. The terrestrial heat flux of 4.9 cal cm^{-2} day^{-1} found by this method of calculation corresponds closely with the value (6.4 cal cm^{-2} day^{-1}) determined at this branch as noted previously.

About one-tenth to one-twentieth of the quantity of snow that was melted on the roofs of the main office building and the observation room was melted by electric heaters and hot water pipes. However the quantities and order of melting were the same regardless of the mode of introduction of the warm air. Table 2 shows a comparison of the amounts of thawing of roof snow by different types of heat sources.

Summary

Observations were made of the so-called "vertical profiles" of the snow on three types of flat roofs during the current winter (winter of 1976-1977). These results were compared with the values determined for the ground.

Although the structure of the snow cover layers on roofs was similar to that of the top layer of the ground snow cover, there were considerable differences in the depths of the snow covers. Granular snow was found at the base layer of the snow cover at all observation points. That is, there were some differences, with thawing occurring at the base of the snow cover due to heat passing up through the roofs of the buildings. In the building in which people were present during the day, there was an average amount of thawing for

TABLE 2:

Comparison of snowmelts on roofs when different types of heat sources were used (The results of the determinations resulting from introduction of warm air, electric heaters and hot water pipes were made at Shinjo. Reference (2) may be consulted for details.)

Heat source and method	Residual heat from heating			Electric heater		Hot water pipe circulation method
	Natural conditions, room temperature 20° C		Warm air introduction, room temperature 20° C	Spreading method 150 $W \cdot m^{-2}$	Ascending method 200 $W \cdot m^{-2}$	Hot water at 40 - 60° C
	Main office building	Observation room				
Quantity of snow melted, $l \cdot m^{-2} \cdot day^{-1}$	2.4	1.2	7.5	24 - 36	22 - 29	12 - 38

the 35 day period of about 3 mm a day (value converted for water column). The amount of heat required to melt this amount only is 23 cal cm^{-2} day^{-1}.

Kojima (1976) found snowmelt values for the roof of a university building with a 1 sun [1.193 inch] slope in Sapporo City, Hokkaido, of 3.1 g cm^{-2} for the 17 day period from 27 January to 12 February 1976 and of 6.6 g cm^{-2} for the 18 day period 13 February to 1 March. The average daily snowmelts were calculated to be 1.8 and 3.7 mm day^{-1}. These values are on the same order as the values of 2.9 and 1.8 mm day^{-1} that we obtained for the roof snow covers of the observation room and the main office building.

The thawing rates of the roof snow covers of the building that was heated during the day (office building) and the building that was not heated (equipment storehouse) differed by 2.3 mm day^{-1}. From the standpoint of the load resistance of houses, the load of 210 kg per 1 m^2 on the equipment storehouse on 13 January was an excessive snow load, whereas the load of 130 kg on the office building, from which there was active melting and drainage, was about 60% of the load on the former building. That is, a difference of 80 kg m^{-2} occurred in the snow loads on these roofs. Therefore, this value must be taken into consideration in the design of buildings.

For the period from December up to mid-January of this year, the snowmelt at the base of the ground snow cover was calculated to be about 0.62 mm day^{-1} (water column value) from the results of observations of the vertical profile of the ground snow cover. This melting was considered to be entirely the result of terrestrial heat. When the terrestrial heat flux was calculated, it was found to be 4.9 cal cm^{-2} day^{-1}, a value highly consistent with the actually measured value of 6.4 cal cm^{-2} day^{-1}.

When the average densities of the snow covers on the three buildings were compared, the highest value, 0.227 g cm^{-3}, was found for the snow on the equipment storehouse, which was downwind of the main office building. The next highest density, 0.211, was found for the snow on the windward side of the roof of the main office buidling, whereas the lowest density (0.205) was found for the snow on the roof of the observation room, the roof of which was lowest in height. The value for the ground was 0.218, a value close to those for the main office building and the equipment storehouse. Thus, there were no great differences among these four densities, which were within a range from 0.21 to 0.23 g cm^{-3}.

Thus, the roof snow covers were of somewhat greater hardness than the ground snow, perhaps because of the hardening action of the wind.

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2. Administrative Bureau, National Research Center for Disaster Prevention: "Toshi no setsugai boshi ni kansuru sogo kenkyu hokokusho" (General research report on prevention of snow damage in cities), 184 pages. Refer to pages 144-147 (1975).

3. K. Kojima: "Murakusetsu yanejo no sekisetsu to sono yukai" (Snow cover and melting on roofs from which snow has not been removed). Collected Papers of the Autumn Meeting of the Japanese Snow Ice Society (No. 221) (1976). (Received 26 December 1977)

4. UNESCO: Seasonal Snow Cover, pp. 1-38 (1970).

Appendix

Hardness of the snow cover (The values for roof snow were obtained by converting the numerical values determined with a Yotei hardness meter to values as obtained by Kinoshita hardness meter using a correction table.[1])

1 庁舎屋上			2 観測室屋上			3 器材庫屋上			4 平地上		
HS (cm)	R ($g \cdot f \cdot cm^{-2}$)	$\log_{10}R$ (C.G.S.)	HS (cm)	R ($g \cdot f \cdot cm^{-2}$)	$\log_{10}R$ (C.G.S.)	HS (cm)	R ($g \cdot f \cdot cm^{-2}$)	$\log_{10}R$ (C.G.S.)	HS (cm)	R ($g \cdot f \cdot cm^{-2}$)	$\log_{10}R$ (C.G.S.)
41	54	1.7	65	50	1.7	73	61	1.8	98	5.4	0.73
42	35	1.5	52	130	2.1	61	240	2.4	90	15	1.2
41	82	1.9	37.5	700	2.9	50	1200	3.1	80	27	1.4
40	94	2.0	30	3000	3.5	37	4300	3.6	70	100	2.0
29	330	2.5	24	1500	3.2	28	2500	3.4	60	107	2.0
28	240	2.4	18	52	1.7	18	1900	3.3	50	300	2.5
29.5	330	2.5	9.5	800	2.9	12	1700	3.2	40	530	2.7
27	290	2.5							30	1370	3.1
10	2400	3.4							20	1430	3.2
11.5	2000	3.3							14	2050	3.3
12	2900	3.5							7	610	2.8
12.5	2700	3.4									

Remarks: HS: Snow depth; R: Hardness, found with a number 101 Yotei hardness meter

1 - Roof of main office building
2 - Roof of observation room
3 - Roof of equipment storehouse
4 - Ground